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(54) Locating moving radio sources

(57) Signals from moving sources are received at two spaced locations *A*, *B*, by respective monopulse antennae 1 each having sum and difference radiation patterns. In order to confirm that the signals received at A and B are from the same source, the two signals are correlated; signals from a single source produce a strong correlation peak, whilst those from different sources cancel out over time. The signals are also frequency analysed. The bearings of a source can be determined by scanning both the antennae to obtain minima in the associated components of the spectra derived from the difference patterns when the source is located in the central nulls thereof. The position with respect to each location may alternatively be determined by combining scanning with determining the phase difference between the signals received by the two antennae, the phase difference being between appropriate spectral components derived from the frequency analysis.

The velocity of a source can be found by receiving signals at a third spaced location (*C*, Fig 8) and determining the two respective differences between the Doppler shifts of the signals received at two pairs of the three locations *A*, *B*, (*C*).

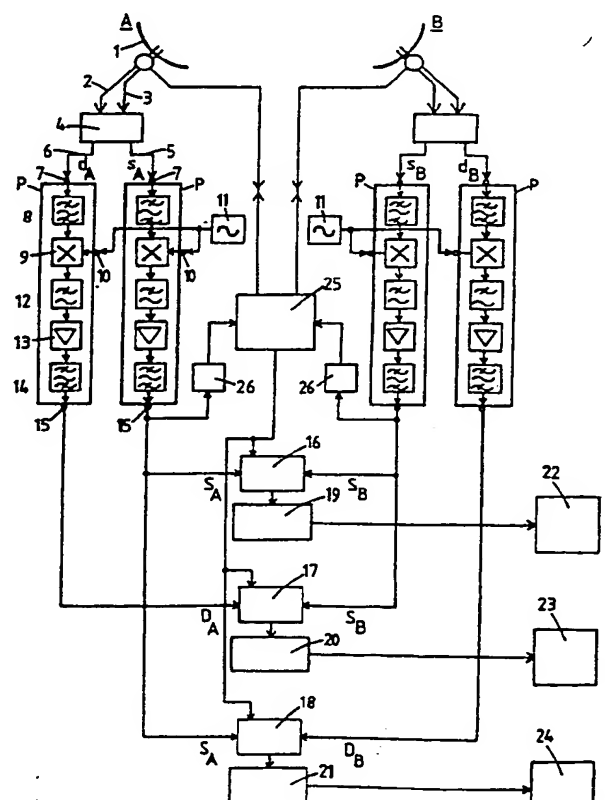

FIG. 1

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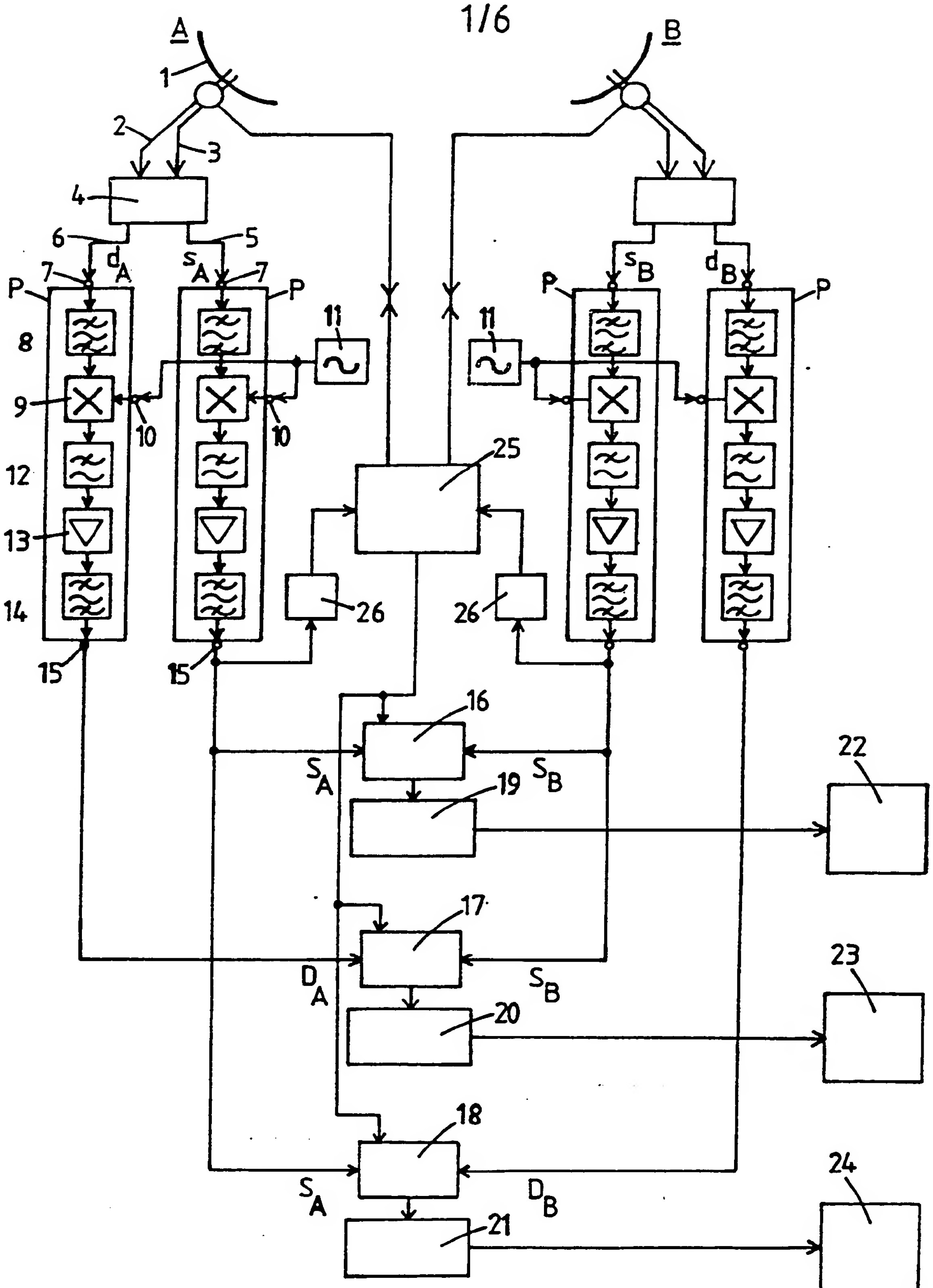
A
B
1
2
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d_A
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14
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S_A
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24

FIG. 1

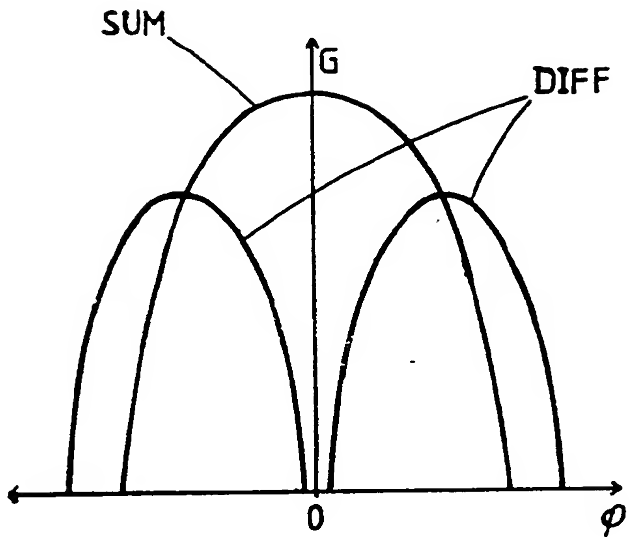

FIG. 2

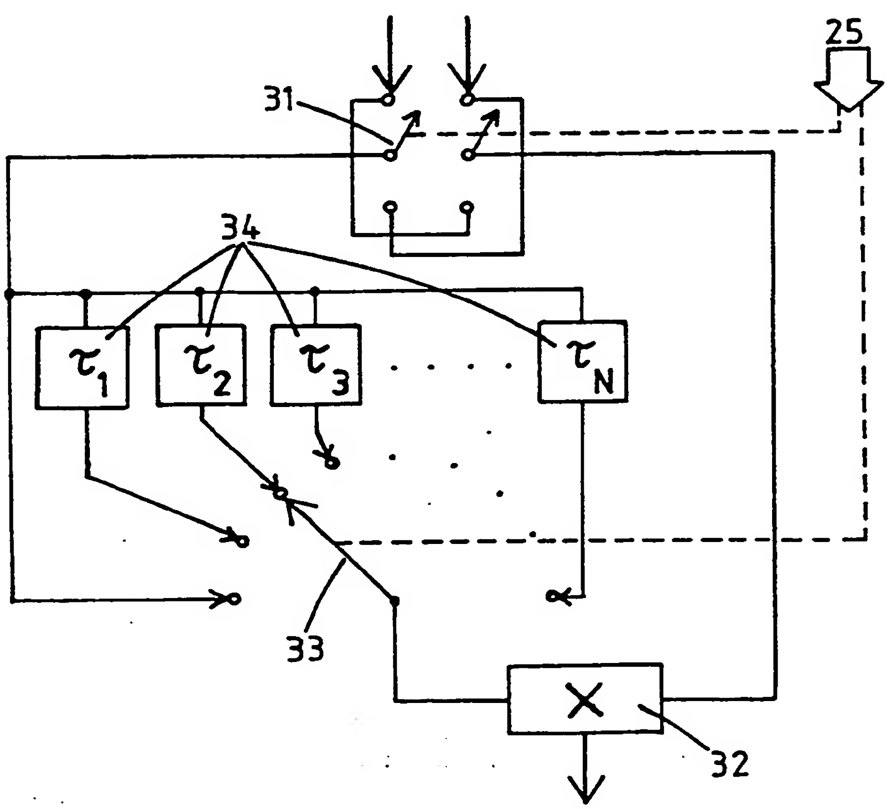

FIG. 3

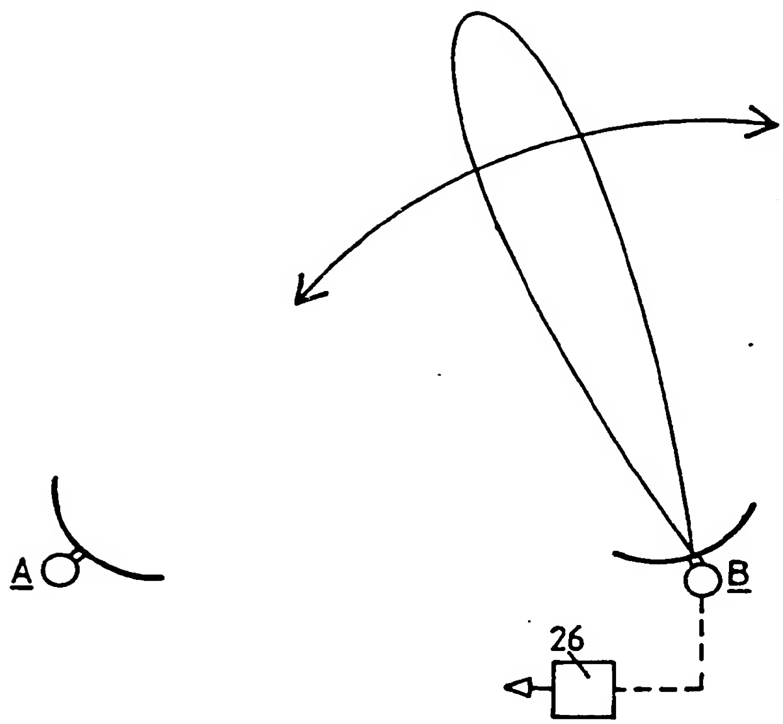

FIG. 4

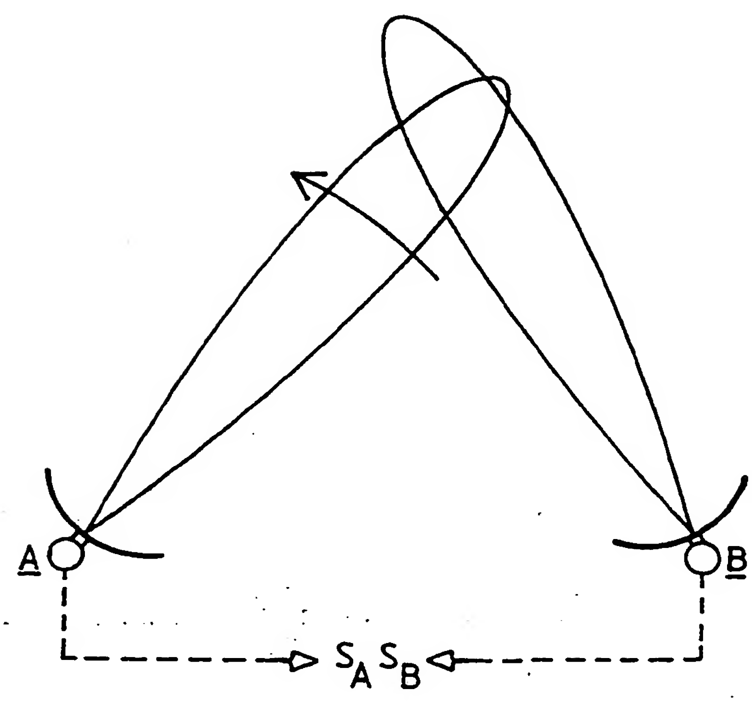

FIG. 5

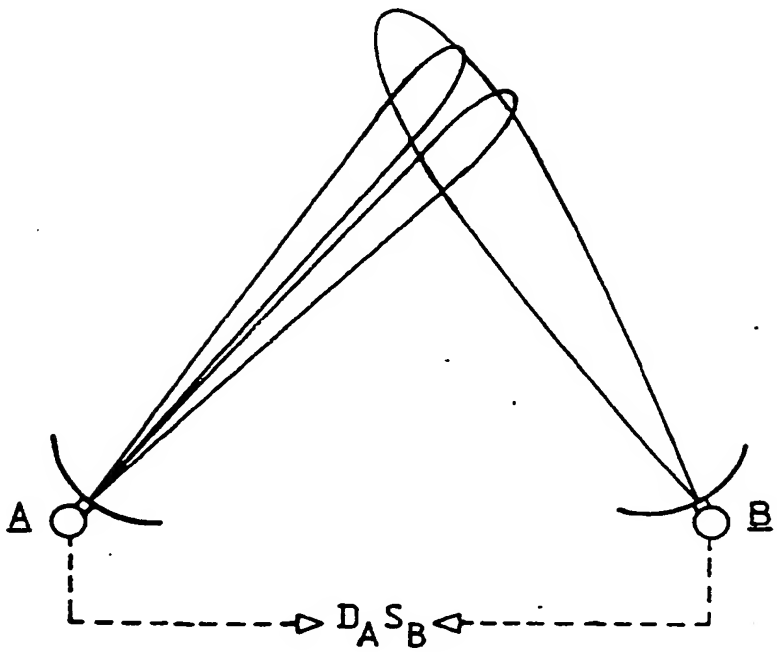

FIG. 6

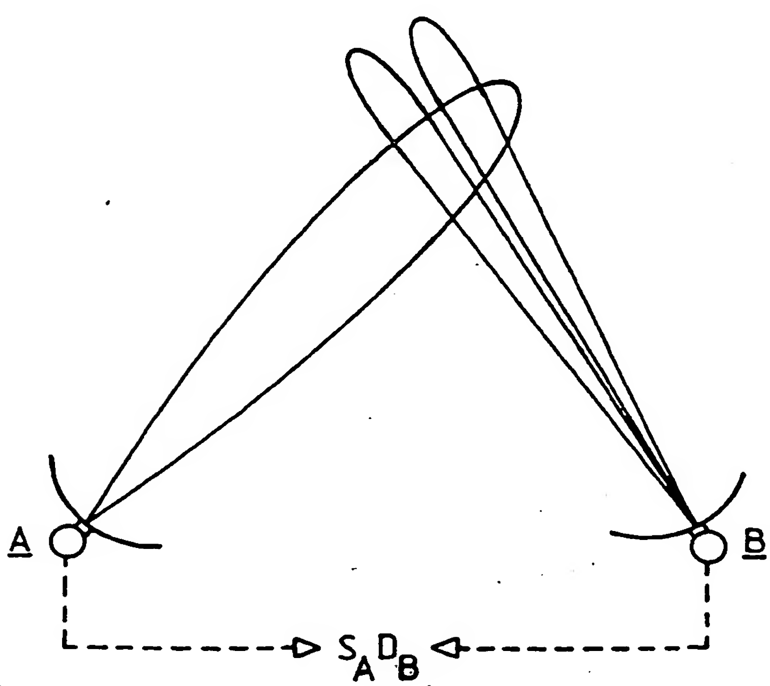

FIG. 7

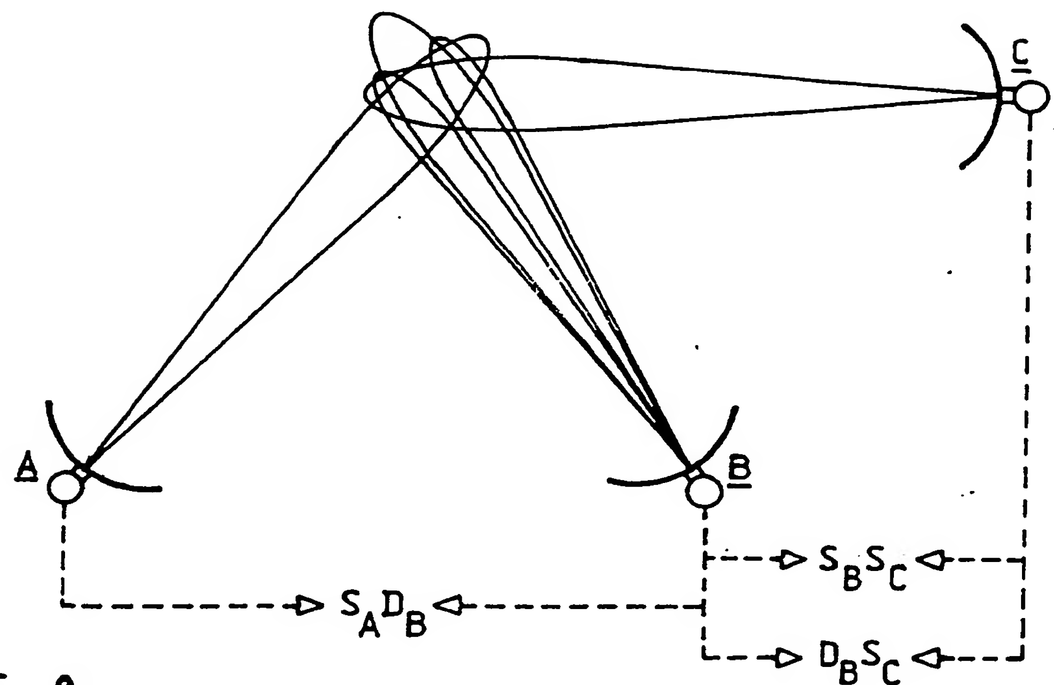

FIG. 8

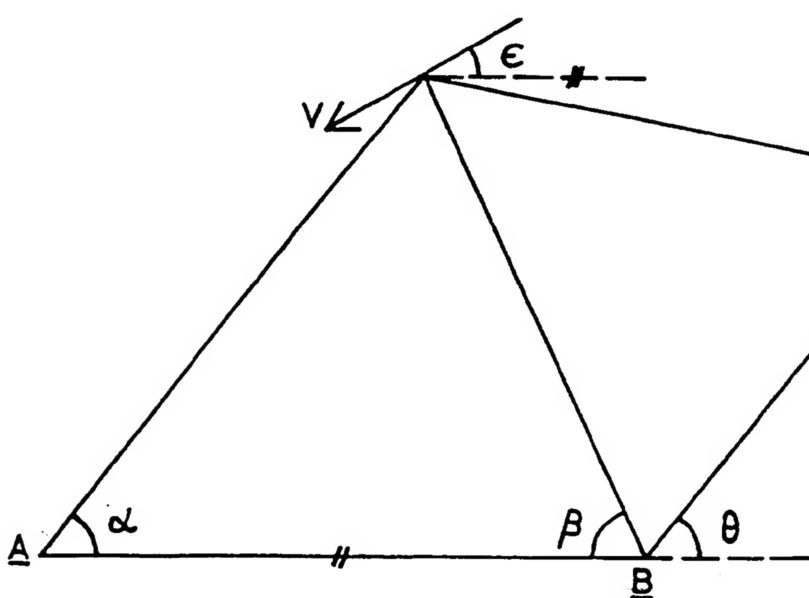

FIG. 9

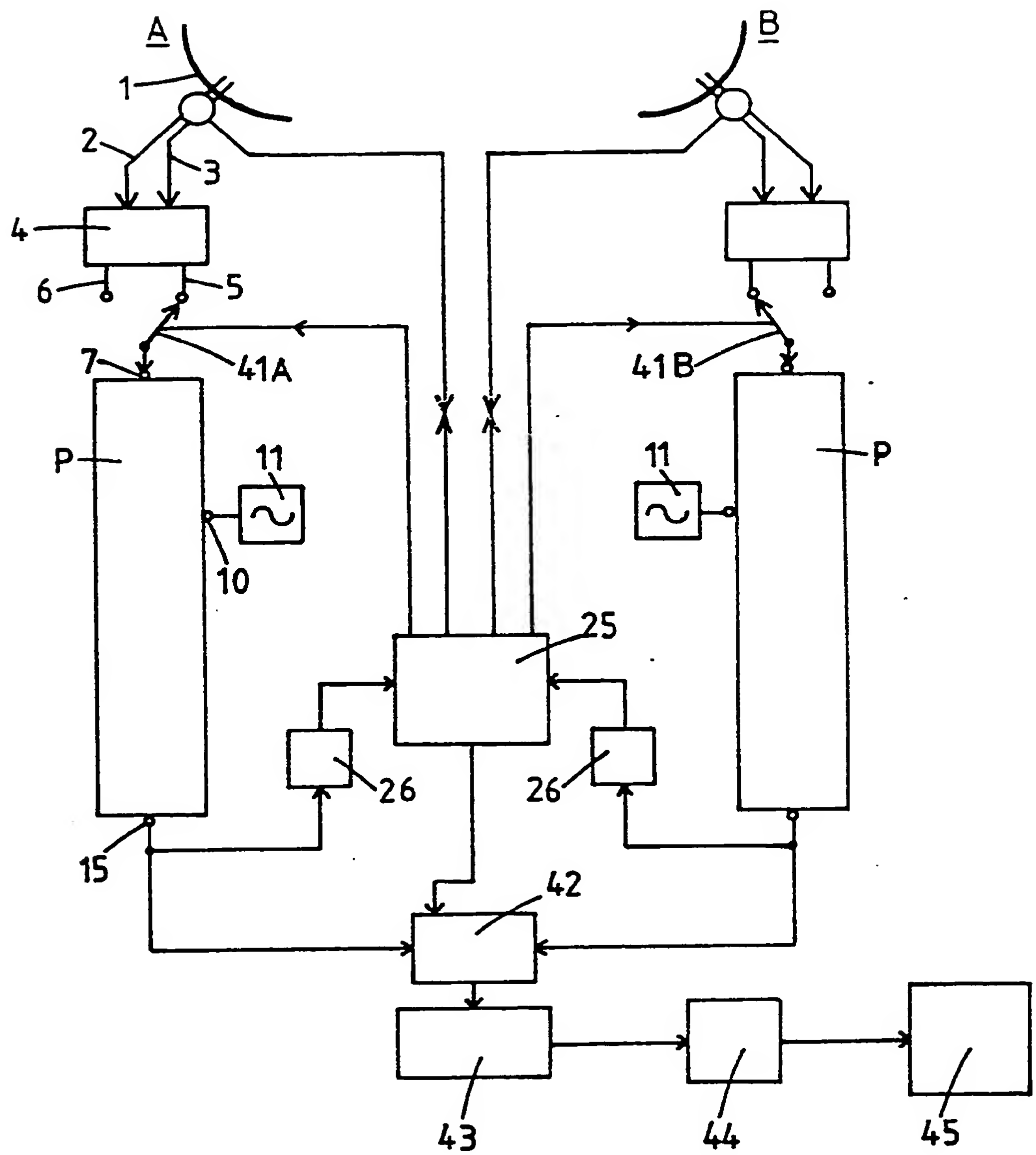

FIG. 10

"LOCATING MOVING RADIO SOURCES"

The invention relates to methods of locating radiating radio sources with reference to a plurality of spaced locations, said sources moving relative to said locations, and is particularly but not exclusively applicable to locating and distinguishing between a plurality of such sources which are each radiating radio signals over a common range of frequencies and which may therefore not be distinguishable by the frequencies of their respective radiated signals. The invention further relates to a method of deriving the direction of motion and/or speed of such sources, and to systems for performing the methods.

Known methods of locating such sources may be divided into two groups:-

(i) Direction finding from a plurality of locations, using antennae with narrow beams which can be scanned; the position of a source is determined by locating it at the intersection of two beams. If more than one source is present, this method requires the use of antennae at a number of locations at least one greater than the number of sources in order to be able to distinguish between occupied and unoccupied beam intersections, which is clearly impracticable with more than a few sources.

(ii) The difference between the times of arrival at two locations of corresponding signals from a source may be determined by a broad-band correlation, thereby locating the source on a hyperbola; the position of the source on the hyperbola may then be determined by direction-finding from the two locations, or by broad-band correlation of signals received at one of the two locations and at a third location, thereby defining a second hyperbola intersecting the first. For radiation over a substantial band of frequencies, the accuracy of such a method deteriorates as the bandwidth and integration time of the correlation decrease, which means that the method inherently requires expensive

equipment and tends to be slow if there is to be any possibility of reasonable accuracy. Furthermore, modulation of a radiated signal can broaden the response in the time domain, thereby degrading accuracy, or produce multiple responses which effectively define additional, anomalous hyperbolae and which furthermore make it difficult or impossible to distinguish between different sources.

It is an object of the invention to alleviate the above disadvantages.

According to a first aspect of the invention, a method of locating radiating radio sources with reference to a plurality of spaced locations, said sources moving relative to said locations, comprises:-

receiving radiated signals with radiation patterns of antenna means at said locations and deriving from corresponding signals radiated by the same moving radio source and received respectively at two said locations, the corresponding signals being within a predetermined narrow frequency band, a set of at least two correlation signals each representative of a correlation between the corresponding signals, wherein the reception of the radiated signals and the derivation of the correlation signals includes the selection of different regions so that each correlation signal represents the presence of at least one said source in a respective said region, the different regions overlapping so as to have in common a region of overlap that is smaller than at least one of said different regions, and wherein the correlation signals each have components at one or more frequencies dependent on the difference between the Doppler shifts of the corresponding signals received respectively at the two locations, and

obtaining an indication that the same said difference between the Doppler shifts is represented by at least one respective component of each correlation signal,
whereby substantially to establish the presence of a said source in the common region of overlap.

Correlation may be used to establish whether or not signals of arbitrary character received at two spaced locations originate

from the same source. This may be done by multiplying together the signals received at the two locations (or signals derived therefrom, e.g. at an intermediate frequency) after subjecting one signal to a delay relative to the other, and integrating the product. If the received signals do not originate from the same source, the resulting quantity will be of small magnitude and noise-like in character for all values of delay, representing the correlation of independent signals which by chance are similar for short periods of time. However, if the received signals do originate from the same source, the resulting quantity will have a substantial amplitude over a small range of delay times, with a maximum for a value of delay equal to the difference (which may be zero) in the times of arrival at the two locations of corresponding signals radiated at the same instant by the source, and decreasing to the above-mentioned small amplitude at values of the delay time progressively further from that of the maximum. The source is thereby located approximately on a hyperbola defined with reference to the two locations. The width of the peak in the time domain, i.e. as a function of the delay time, increases as the bandwidth of the signals that are multiplied together decreases, and represents an uncertainty in the exact appropriate value of the delay time, thus defining a region straddling the hyperbola within which the source may lie.

In the case of a moving source, a signal of a particular frequency radiated by the source will, as received at a given location, in general be subjected to a Doppler shift, the shift being dependent on the radial velocity of the source with respect to that location; this radial velocity is determined by the speed and direction of motion of the source. The Doppler shifts of signals received from a moving source at two spaced locations will in general be different, and the above-mentioned peak in the time domain will be modulated at a frequency equal to the difference.

The above-described correlation process may be used to establish the presence of at least one source in a first, fairly large region. If the antenna radiation patterns used to receive the signals at the two locations are not highly directional, the region may be defined

mainly by the uncertainty in the exact value of the delay time that is required for maximum correlation. However, if one or both of the radiation patterns is at least fairly directional, the region may be at least partly defined by the area of overlap of the beams of the respective antennae; if the region determined by the correlation process does not include the whole of the area of overlap of the beams, the first region will also be partly determined by the correlation process.

In order to establish the location of a source in the first region more precisely, the correlation process may also be carried out for a second region which differs from but at least partly overlaps the first region so that they have in common a region which is smaller than at least the first region. The second region may for example be similar in size to the first region but differently positioned, or it may for example be substantially smaller than and positioned wholly within the first region. The second region may be defined in a similar manner to the first region. If the regions are defined mainly by the respective associated correlation processes, different overlapping regions may be selected by searching for indications of correlation at nominally different delay times sufficiently closely spaced in the time domain for correlation of signals from a single source to be indicated at two adjacent delay times. Preferably the selection of different regions comprises the reception of radiated signals with at least two different radiation patterns of the antenna means at at least one of the locations.

Having obtained two correlation signals which respectively represent the presence of at least one source in two different overlapping regions, the problem remains of determining whether the correlations are due to the presence of at least one source in the part of each region not common to both, or to at least one source in the common region or to a combination of at least one source in the part of at least one of the regions not common to both and to at least one source in the common region. The invention provides a solution to this problem by utilising the modulations of the correlation signals due

to the difference between the Doppler shifts at the two locations of corresponding signals radiated by a moving source, as explained above. An analysis indicates that for a source at a given position, the difference frequency varies markedly with the speed of the source and with its direction of motion relative to the two locations, and for a source with a given speed and direction of motion, varies fairly rapidly with the position of the source relative to the two locations. It is considered very unlikely that two moving sources, sufficiently far apart each to be in a respective one of the two regions but not in the common region of overlap, would produce the same difference between the Doppler shifts of their corresponding signals received at the two locations. Hence obtaining an indication that the correlation signals respectively associated with the two overlapping regions each have a component representing the same difference between the Doppler shifts substantially establishes that the respective components are due to at least one source present in the common region of overlap; conversely, if there is a difference between Doppler shifts that is represented by a component of one correlation signal but not the other, that component represents the presence of at least one source which lies in the one associated region but not the other.

The requisite indication may be obtained by, for example, frequency-analysing the low-frequency portion of each correlation signal and displaying each resultant spectrum on a cathode-ray tube.

It should be noted that although the processes of locating a source in the first region and in the second region have for simplicity been explained immediately above as sequential processes, the processes may in practice suitably be performed simultaneously.

To increase the accuracy with which the location of a source is known, the method suitably further comprises scanning a said radiation pattern so as to obtain a turning point in the magnitude of at least one said respective component of a said correlation signal derived from a said signal received with the radiation pattern being scanned, whereby to locate a said source substantially at a turning point in the magnitude of the radiation pattern being scanned. The method

may comprise scanning a said radiation pattern at each of said two locations so as to obtain substantially simultaneous turning points in the magnitudes of at least one said respective component of each of two said correlation signals derived from corresponding signals received with the radiation patterns being scanned respectively at the two locations, the same said difference between Doppler shifts being represented by at least one such respective component of each of the two correlation signals, whereby to locate a said source substantially at a respective turning point in the magnitude of each of the radiation patterns being scanned.

Suitably, a said radiation pattern has a single narrow main lobe. Suitably also, a said radiation pattern has a pair of closely-spaced narrow main lobes. Such radiation patterns may be provided at a location by a monopulse antenna having a sum pattern and a difference pattern.

A first of the correlation signals may be derived from corresponding signals received at each of the two locations with a respective radiation pattern having a single narrow main lobe, and a second of the correlation signals be derived from corresponding signals received respectively at a first of the two locations with a radiation pattern having a single narrow main lobe and at the second location with a radiation pattern having a pair of closely-spaced narrow main lobes. A third correlation signal may be derived from corresponding signals received respectively at the first location with a radiation pattern having a pair of closely-spaced narrow main lobes and at the second location with a radiation pattern having a single narrow main lobe. In a method embodying the invention in which a radiation pattern at each of the two locations is scanned, suitably that radiation pattern is one having a pair of closely-spaced narrow main lobes and the substantially simultaneous turning points are minima, whereby said source may be located substantially at the minima in the magnitudes of the radiation patterns between the two main lobes of each pair.

In order to derive the direction of motion and/or speed of a said source, a method embodying the invention may further comprise

deriving from corresponding signals radiated by the same said source and received respectively at one of said two locations and at a third said location, the corresponding signals being within the predetermined narrow frequency band, at least one further correlation signal representative of the presence of said source in a respective further region including at least part of said common region of overlap, and

deriving from at least one of said set of correlation signals and from at least one said further correlation signal the respective differences between the Doppler shifts of the pairs of corresponding signals, radiated by the same said source, from which those correlation signals are derived. Such a method may comprise the process of scanning at one of said two locations a radiation pattern receiving radiated signals from which one of said set of correlation signals and a said further correlation signal are derived, and deriving said respective differences between the Doppler shifts of the pairs of corresponding signals from the frequencies of the respective components of those correlation signals that have simultaneous turning points as the radiation pattern is scanned. In a case wherein, in said process, each of those correlation signals has a plurality of components that have simultaneous turning points as the radiation pattern is scanned, the method may further comprise determining for each of those correlation signals the frequency about which the respective frequencies of its components having simultaneous turning points are symmetrical.

In a method embodying the invention, the frequencies of corresponding signals received at each of the two locations within the predetermined narrow frequency band may be subjected to respective frequency translations differing by an amount greater than the largest said difference between the Doppler shifts to be detected, so that motions in opposite directions can readily be distinguished.

According to a second aspect, the invention provides a system for locating radiating radio sources with reference to a plurality of spaced locations, said sources moving relative to said locations, the system comprising

at each of said locations, antenna means having a radiation pattern for receiving radiated signals;

means for predetermining a common narrow frequency band within

the frequency range of reception of each radiation pattern;

means for deriving from corresponding signals radiated by the same moving radio source and received respectively at two said locations, the corresponding signals being within the predetermined frequency band, a set of at least two correlation signals each representative of a correlation between the corresponding signals;

wherein the aforesaid means comprise means for selecting different regions so that each correlation signal represents the presence of at least one said source in a respective said region, the different regions overlapping so as to have in common a region of overlap that is smaller than at least one of said different regions, and wherein the correlation signals each have components at one or more frequencies dependent on the difference between the Doppler shifts of the corresponding signals received respectively at the two locations, and

means for indicating that the same said difference between the Doppler shifts is represented by at least one respective component of each correlation signal,

whereby substantially to establish the presence of a said source in the common region of overlap.

Said means for deriving a set of at least two correlation signals may comprise delay means for delaying a signal derived using a radiation pattern at one of the two locations by a selected one or more of a plurality of different delay times relative to a signal derived using a radiation pattern at the other of the two locations, means for multiplying the relatively undelayed signal with the signal relatively delayed by the selected one delay time or separately with the signal as respectively relatively delayed by each of the selected delay times, means for controlling the orientations of the radiation patterns of the antenna means at the two locations, and means for selecting said one or more delay times in accordance with said orientations so that in operation said different regions are selected substantially wholly by said different radiation patterns.

The invention will now be further explained and embodiments thereof

described by way of example with reference to the diagrammatic drawings, in which:-

Figure 1 is a schematic diagram, mainly in block form, of a first system embodying the invention ;

Figure 2 illustrates a central portion of a pair of radiation patterns of a monopulse antenna;

Figure 3 shows in greater detail a correlator for use in the embodiment of Figure 1;

Figures 4 to 8 inclusive illustrate schematically stages in the performance of methods embodying the invention;

Figure 9 shows parameters used in deriving the speed and the direction of motion of a source, and

Figure 10 is a schematic diagram, mainly in block form, of a second system embodying the invention.

Referring to Figure 1, a system embodying the invention comprises the same equipments at each of two spaced locations A and B, signals from the equipments being supplied to further apparatus at a common signal evaluation and control location. The spacing between A and B is generally of the same order of magnitude as, or rather less than, the distances from A and B of sources which it is desired to locate. The equipment at each location comprises (referring to location A in Figure 1) a steerable monopulse reflector antenna 1 having two transversely-spaced feeders 2 and 3 connected to respective inputs of a hybrid device 4. At two outputs 5 and 6 of the hybrid device are produced respectively the sum and difference (denoted s and d respectively, with subscript of the location) of the signals applied to the inputs of the hybrid device. These sum and difference signals are respectively supplied to the inputs 7 of two identical circuit blocks P. As shown for the circuit block processing the difference signal d_A, each signal is first limited in bandwidth by a bandpass filter 8, and is then mixed in a mixer 9 with a signal of similar frequency supplied to a further input 10 of the circuit block P from a local oscillator 11 which is common to the two circuit blocks at that location and whose frequency stability is high; the mixer thereby produces a signal at an intermediate frequency. The latter signal is

fed through a low-pass filter 12, which removes signal components at the image frequency, to an amplifier 13 and thence to a band-pass filter 14 which limits the bandwidth to a narrow range of frequencies. The resultant signals at the respective outputs 15 of circuit blocks P are denoted S for the signal derived from the sum of the signals in feeders 2 and 3 of antenna 1, and D for the signal derived from the difference between the signals in the feeders 2 and 3, in each case with the subscript of the respective location.

The output signals from the above-described equipments at locations A and B are supplied to further, common apparatus which may be at A or B or be remote from both. The output signals from the circuit blocks P at the two locations form input signals for three correlation devices 16, 17 and 18, signals S_A and S_b being fed to respective inputs of correlation device 16, signals D_A and S_B being fed to respective inputs of correlation device 17, and signals S_A and D_B being fed to respective inputs of correlation device 18. The outputs of the correlation devices are respectively connected to three frequency analysers 19, 20 and 21 whose outputs can be shown in graphical form on respective displays 22, 23 and 24.

A control unit 25 controls and monitors the directions in which the antennae 1 at A and B point: it also controls the correlation devices 16, 17 and 18 (as will be explained below) and receives signals from detectors 26 respectively supplied with the signals S_A and S_B.

Figure 2 shows the form of typical radiation patterns of a monopulse antenna around boresight, gain G (exceeding an arbitrarily selected level) being plotted against angle φ off boresight. The addition of the signals in the two feeders of the antenna produces the sum beam pattern denoted SUM, and the subtraction one from the other of the signals in the two feeders produces the pattern of difference beams denoted DIFF. It will be seen that there is very sharp minimum on boresight in the difference beams pattern, which may enable the bearing of a source to be determined to within one-tenth of the half-power beamwidth of the sum beam, the latter angle being for example about 6° for a 1 metre diameter reflector antenna operating at 3GHz.

The area of intersection of two radiation patterns of the antennae at A and B may be considered to be the area from within which a source radiating a specified power will produce signals of not less than a given power at each location.

Figure 3 shows schematically one form of correlation device for the system of Figure 1. The input signals to the device are supplied therein to a change-over switch 31 which enables either one of the input signals to be applied directly to one input of a multiplier 32 while the other input signal is applied to the other input of the multiplier after being subjected to a relative delay (which may be zero) selected by means of a selector switch 33 having (N + 1) inputs and a single output. One input of the selector switch 33 is connected directly to one output of the change-over switch 31; the other inputs of the selector switch 33 are connected to that same output of switch 31 via a respective one of a set of N delay lines 34 providing delays $\tau_1, \tau_2, \tau_3, \ldots \tau_N$.

Referring again to Figure 1, the correlation signals at the outputs of correlation devices 16, 17 and 18 are for convenience denoted $\underline{S}_A\underline{S}_B$, $\underline{D}_A S_B$ and $\underline{S}_A\underline{D}_B$ respectively, it being understood that one input signal to each correlation device is subjected therein to an appropriate delay (which may be zero) relative to the other, the appropriate delay being selected as will now be explained.

As mentioned above, the control device 25 controls and monitors the orientations of the antennae at A and B. The difference between the distances from A and B of the area of intersection of the sum beams of the two antennae, and hence the difference between the times of arrival at A and B of corresponding signals radiated by a source in that area, can be calculated for appropriate combinations of the respective orientations of the two antennae: the control device accordingly selects in each correlation device the appropriate position of the change-over switch 31 (hence determining the signal derived from which of the two antennae is to be delayed relative to the other) and the appropriate position of selector switch 33 (hence determining the value of the delay).

In operation, the frequency of corresponding signals within a

narrow frequency band received at A and B from a moving radio source will be Doppler-shifted at at least one (and generally both) of the locations by an amount dependent on the radial component of velocity of the source with respect to the location and on the frequency of transmission; the sense of the Doppler shift, i.e. whether to a higher or to a lower frequency, depends on whether the radial component of velocity is towards or away from the location. The circuit block P at each location provide filtering to define the frequency band which has been Doppler-shifted, and also provides convenient translation to a lower frequency and amplification. When two signals respectively from one circuit block P at each of the two locations are multiplied together after subjecting one signal to a suitable delay relative to the other, the resultant correlation signal will include a modulation component having a frequency dependent on the difference between the Doppler shifts of the received signals. The frequency of this modulation component is determined by the frequency analyzer connected to the output of the correlation device, and is shown in graphical form on the associated display. If the frequency translations provided by the local oscillators 11 at the two locations are the same, the frequency of the modulation component will equal the difference between the Doppler shifts of the received signals irrespective of the sense of the difference, and will be zero if the difference between the Doppler shifts is zero. Suitably, the frequency translations provided by the local oscillators are not the same but differ by an amount greater than the largest likely difference between the Doppler shifts of the received signals (taking account of the senses of the Doppler shifts), so that the frequency of the modulation component in the output of the correlation device will equal the sum of the difference between the frequency translations of the local oscillators and the difference between the Doppler shifts (taking account of the sense of the latter); if the difference between the Doppler shifts is zero, the frequency of the modulation component will then equal the difference between the frequency translations. Such an arrangement is useful for distinguishing between Doppler shift differences of equal magnitude but opposite sense.

As mentioned above, any particular value of the difference in times of arrival at two spaced locations of corresponding signals from the same source limits the possible position of the source to a corresponding hyperbola. Thus if a source may lie anywhere within a given area, the exact value of delay that would produce maximum correlation between signals from the source will vary across the area. However, as also mentioned above the width of the correlation peak in the time domain is not insignificant, the width between -3dB points being equal to the reciprocal of the bandwidth of the signals. Therefore by selecting a series of specific different values of delay time adjacent one to another such that in the time domain, a correlation peak at each of those values would intersect a peak at an adjacent value of the series at for example 3dB below their maxima, it can be ensured that the correlation signal for any value of delay over the whole range covered by the series of specific values will have a magnitude not more than 3dB below the value it would have if the value of delay were exactly right. The total area within which it is desired to locate moving sources may be considered to be divided into a set of contiguous strips each extending on both sides of a respective hyperbola corresponding to each delay time value of the series. Depending on the parameters of a particular system, the widths of the strips may be such either that the area of intersection of radiation patterns of the antennae at two locations, for example their sum beams, generally lies wholly within a single strip, or that the area of intersection generally straddles two or more adjacent strips. In the former case the region, from sources within which corresponding signals are correlated, is effectively determined wholly by the antenna radiation patterns; in the latter case it may be determined partly or predominantly by the selected correlation delay. Where the area of intersection of the antenna radiation patterns straddles two or more adjacent strips, it may be desired that the region, from sources within which corresponding signals are correlated, should nevertheless be determined wholly by the antenna radiation patterns: this may be done by, for example, providing a correlation device with a plurality of multipliers and in

operation simultaneously connecting one input of each multiplier to the output of a respective one of an appropriate selected group of adjacent delay lines which provide a set of different values of delay time adjacent one to another, and adding together the outputs of the multipliers. As a further alternative, one input signal to the correlation device may be switched successively to the input of each of such a selected group of delay lines, so that the correlation device produces sequentially the correlation signal resulting from each of the set of different values of delay time.

The system produces a response only to those signals received in the selected narrow frequency band at A and B which (with an appropriate delay of one relative to the other) are coherent and therefore originate from the same source; it will not respond to incoherent signals even if, for example, they are synchronously amplitude-modulated.

Methods embodying the invention will now be described with reference to Figure 4 to 8 (which are not to scale). For simplicity, it is assumed that the region, from sources within which corresponding signals are correlated, is defined wholly by the intersection of the relevant antenna radiation patterns, and not by the delay in the correlation process, and that a single delay time can be used to correlate corresponding signals from a source anywhere in that region. The single main lobe of the sum beam of the antenna at one of the locations, for example at B as shown in Figure 4, is scanned by rotating the antenna over a selected arc (under the control of control unit 25, Figure 1) to search for a radio source radiating within the frequency band of interest. The presence of such a source within the lobe is indicated to the control unit 25 by the output signal of the respective detector 26; the control unit may comprise means for analyzing the detected signal to determine whether the source is of a particular type of interest. While retaining the source within the sum beam of the antenna at B, the sum beam of the antenna at A is now scanned so as to intersect the sum beam of the antenna at B in a region which is moved progressively along the latter beam, as depicted in Figure 5. During this scanning, the

correlation device 16 is controlled by the control unit 25 as explained above as to provide a delay of one input signal to the correlation device relative to the other input signal appropriate to the position of the region of intersection. The low-frequency spectrum of the output signal $\underline{S}_A\underline{S}_B$ of this correlation device is analyzed by frequency analyzer 19 and is displayed on the display 22. When one or more peaks appear on this display, this indicates that at least one moving source lies within the region of intersection of the sum beams of the antennae at A and B; the angular orientations of the antennae give coarse bearings of the source(s) with respect to A and B, and hence a rough location of the source(s).

The time delay in correlation device 17 which multiplies $\underline{D}_A$ and $\underline{S}_B$ is set to the same value as in correlation device 16. (The control unit 25 may simultaneously select the same delay in each of the three correlation devices). The output signal $\underline{D}_A\underline{S}_B$ of correlation device 17 is similarly frequency-analyzed by analyzer 20 and the resultant spectrum displayed on display 23. The displays 22 and 23 indicate whether the two spectra have respective components at one or more common frequencies: the presence of a component in each spectrum at a common frequency establishes the presence of a moving source both in the region of intersection of the sum beams of the antennae at A and B with one another and in the region of intersection of the sum beam of the antenna at B with the pair of difference beams of the antenna at A. Since these two regions overlap so as to have in common a region that is smaller than the region of intersection of the sum beams of the antennae at A and B, the uncertainty in the exact position of a source has been reduced. Moreover,the uncertainty can be reduced further (and in this case to a greater extent) by monitoring a component in the spectrum of $\underline{D}_A\underline{S}_B$ at a frequency common to a component in the spectrum of $\underline{S}_A\underline{S}_B$ while the angular orientation of the antenna at A is adjusted, suitably so that each difference beam of the antenna at A moves back and forth within (or otherwise scans) the arc subtended by the sum beam at the angular orientation of the antenna which gave the

coarse bearing of the source, as depicted in Figure 6. When a component in the spectrum of $\underline{D}_A\underline{S}_B$ at such a common frequency attains a minimum, a source must lie within the small portion of the region of intersection of the sum beams of the antennae at A and B that is disposed centrally between the difference beams of the antenna at A: the angular orientation of the antenna at A which produces this condition thus gives a fine bearing of the source with respect to A.

Simultaneously or immediately afterwards, an analogous procedure is performed with the pair of difference beams of the antenna at B, as depicted in Figure 7, monitoring the spectra on displays 22 and 24. The angular orientation of the antenna at B which produces a minimum in one or more components of the spectrum of $\underline{S}_A\underline{D}_B$ at frequencies common to components in the spectrum of $\underline{D}_A\underline{S}_B$ that attain a minimum when the pair of difference beams of the antenna at A is scanned gives a fine bearing of the source with respect to B. The fine bearings give the accurate location of the source with respect to A and B.

The presence in the spectra of $\underline{S}_A\underline{S}_B$ and of $\underline{D}_A\underline{S}_B$ and/or $\underline{S}_A\underline{D}_B$ of components at more than one common frequency may be due to the presence of a plurality of moving sources in the relevant common region of overlap and/or to modulation of a signal radiated by a source. Different possible cases will now be considered in turn.

1. If, in the spectrum of a correlation signal derived using the pair of difference beams of the antenna at one location, components at a plurality of common frequencies attain minima simultaneously when the pair of difference beams is scanned, then those components are due either to modulation of the signal being transmitted by a source or to the presence in the common region of overlap of a plurality of sources whose movement is such as to produce different differences between the Doppler shifts at A and B but whose bearings, with respect to the location of the antenna being scanned, are so close together as not to be distinguishable even with the relatively high resolution afforded by the pair of difference beams.

(a) In the case of modulation, it is believed that with all forms of modulation, the spectrum will, as regards either the broadening of a peak or the production of distinct further peaks at other frequencies, be symmetrical about the frequency of the single component that would exist in the absence of modulation; furthermore it is thought that with at least the majority of possible forms of modulation, there will be at that one frequency a component which is larger than the other components which are present only as a result of the modulation.

(b) In the case of a plurality of sources which produce different differences in Doppler shifts at A and B but whose bearings with respect to the one location at which the antenna is scanned are indistinguishable, their bearings with respect to the other antenna location may well be distinguishable but in any case their different speeds and/or directions of motion will soon cause their bearings to become distinguishable with the antenna being scanned at the one location.

2. If, in the spectrum of a correlation signal derived using the pair of difference beams of the antenna at one location, components at a plurality of frequencies common to components of the spectrum derived with the sum beam of that antenna do not attain simultaneous minima as that pair of difference beams is scanned, those components must be due to sources which have difference respective bearings within the common region and whose position and/or movement is such as to produce different differences in Doppler shifts at A and B. The locations of those further sources may thus be accurately determined as described above.

Thus it will be understood that individual sources within the area of intersection of respective radiation patterns of antennae at spaced locations may be associated or "labelled" with components of the spectrum of a correlation signal derived from sources within that area. In particular, individual sources within the area of intersection of the sum beams of the antennae may be so "labelled" and an accurate bearing for each source with respect to an antenna location obtained unambiguously with the aid of the pair of difference

beams of the antenna at that location.

Although the display units 22, 23 and 23 have been shown as separate in Figure 1, the outputs signals of at least two of the frequency analyzers 19, 20 and 21 could alternatively be shown simultaneously or sequentially on a single, common display.

It may be noted that since, in the above-described methods, the process of locating a source does not require the appropriate correlation delay between signals received at two locations to be determined with high accuracy, the signal processing is simplified in comparison with a known method which relies on broad-band correlation; in particular, methods and apparatus embodying the invention require only a relatively small bandwidth.

The direction of motion and/or speed of a moving source may be determined with the aid of an antenna at a third location C spaced from the locations A and B. An arrangement like that in Figure 1 may be used to correlate signals received at C with corresponding signals received at A and/or B. The parameters of direction of motion and/or speed may then be derived from the respective differences between the Doppler shifts of corresponding signals received at different pairs of locations. Knowing the difference between the frequency translations provided at the two locations of each pair in deriving an intermediate-frequency signal from a received signal, the requisite Doppler shift differences can be obtained from the appropriate spectra. Considering as a specific example a system which enables corresponding signals at B and C to be correlated, we may denote the difference between the Doppler shifts at A and B, i.e. the amount by which the frequency of a radiated signal as received at A exceeds the frequency of a corresponding signal as received at B, as F_{AB}, and similarly the difference between the Doppler shifts at B and C, i.e. the amount by which the frequency of the signal received at B exceeds the frequency of a corresponding signal as received at C, as F_{BC}. Then, by for example scanning the pair of difference beams of the antenna at B, F_{AB} can be derived from the frequency of the single component of the spectrum of S_AD_B that is at a frequency common to a component of the spectrum of S_AS_B and that has a minimum when the source is located between the difference beams, or from the frequency about which

components of the spectrum of $\underline{S}_A\underline{D}_B$, that are at frequencies common to components of the spectrum of $\underline{S}_A\underline{S}_B$ and that have simultaneous minima when the source is located between the difference beams, are symmetrical (or from the frequency of the largest of those components in the spectrum of $\underline{S}_A\underline{D}_B$): Knowing the location of a source from its bearings with respect to $\underline{A}$ and $\underline{B}$, the antenna at $\underline{C}$ can be directed at the source and the presence of components at one or more common frequencies detected in the spectra of $\underline{S}_B\underline{S}_C$ and $\underline{D}_B\underline{S}_C$, as depicted in Figure 8. If there is only a single component in each spectrum, and the accuracy with which the antenna at $\underline{C}$ is directed is sufficient to ensure that the source of interest lies within the region of intersection of the sum beams of the antennae at $\underline{B}$ and $\underline{C}$, $\underline{F}_{BC}$ can be derived from the frequency of that component. In general, however, there may be several components. The relevant component or components may be determined by scanning the pair of difference beams of the antenna at $\underline{B}$ and comparing the spectra of $\underline{S}_B\underline{S}_C$ and $\underline{D}_B\underline{S}_C$: the relevant components are those of the spectrum of $\underline{D}_B\underline{S}_C$, at frequencies common to components of the spectrum of $\underline{S}_B\underline{S}_C$, that have minima when the source lies between the difference beams of the antenna at $\underline{B}$ (a state in which appropriate components of $\underline{S}_A\underline{D}_B$ also have minima). $\underline{F}_{BC}$ can be derived from the relevant single frequency or from the plurality of relevant frequencies as explained above for $\underline{F}_{AB}$. Referring to Figure 9 which shows relevant angles, the heading ϵ of the source with respect to the base line $\underline{AB}$ may then be determined from the equation

$$\tan \epsilon = \underline{g}/\underline{h}$$

where $\underline{g} = \underline{u}\cos(\gamma - \theta) - \cos\alpha - (1 + \underline{u})\cos\beta$

and $\underline{h} = \underline{u}\sin(\gamma - \theta) + \sin\alpha - (1 + \underline{u})\sin\beta$

and where $\underline{u} = \underline{F}_{AB}/\underline{F}_{BC}$.

The speed $\underline{V}$ of the source may be determined from the equation

$$\underline{v} = \lambda \underline{w} / [\cos(\alpha - \epsilon) + \cos(\gamma - \theta + \epsilon)]$$

where λ is the wavelength corresponding substantially to the predetermined narrow frequency band,

and $\underline{w} = \underline{F}_{AB} + \underline{F}_{BC}$.

Figure 10 shows a modification of the system of Figure 1, the same reference characters denoting corresponding parts of the systems. As in the embodiment of Figure 1, each of the two locations $\underline{A}$ and $\underline{B}$ is provided with the same equipment which again includes (with reference to location $\underline{A}$) a monopulse antenna 1 with feeders 2 and 3 connected to respective inputs of a hybrid device 4 having outputs 5 and 6 at which are produced $\underline{S}_A$ and $\underline{d}_A$ respectively. In this embodiment, however, there is at each location only a single circuit block $\underline{P}$ whose input 7 can be selectively connected to either output 5 or output 6 of the hybrid device 4 by means of a respective switch 41A, 41B which can by operated by control unit 25. The outputs 15 of the circuit block $\underline{P}$ at each location are respectively connected to the inputs of a correlation device 42 which may be the same as each of the correlation devices 16, 17 and 18 in Figure 1. The output of the correlation device is connected to a frequency analyzer 43, whose output is connected via a store 44 to a display unit 45.

This embodiment can be operated in an anlogous manner to the embodiment of Figure 1, with the obvious difference that the correlation signals $\underline{S}_A\underline{S}_B$, $\underline{D}_A\underline{S}_B$ and $\underline{S}_A\underline{D}_B$ must be derived at different times using the switches 41 at the two locations as appropriate and one or more of the resultant spectra produced by frequency analyzer 43 must be stored in the store 44. The display 45 suitably is capable of displaying two or more spectra simultaneously. Thus, for example, the step in the method of locating a source which requires a comparison of the spectra of $\underline{D}_A\underline{S}_B$ and $\underline{S}_A\underline{S}_B$ while the pair of difference beams of the antenna at $\underline{A}$ is scannned to obtain a fine bearing of the source with respect to $\underline{A}$ may be performed by first forming the correlation signal $\underline{S}_A\underline{S}_B$ in the correlation device 42, frequency-analysing this signal in the analyzer 43, and storing its spectrum in the store 44. The switch 41A may then be changed to enable

the correlation signal $\underline{D}_A\underline{S}_B$ to be formed and the resultant spectrum displayed in real time, simultaneously with the stored spectrum of $\underline{S}_A\underline{S}_B$, while the antenna at $\underline{A}$ is adjusted to find the minimum of one or more components of the spectrum of $\underline{D}_A\underline{S}_B$. This of course assumes that there would not be a significant change in the spectrum of $\underline{S}_A\underline{S}_B$ if it could be analyzed and displayed in real time simultaneously with the spectrum of $\underline{D}_A\underline{S}_B$, and hence the practicability of this embodiment will depend on parameters such as the speed of the source and the time taken to analyse the correlation signal.

The frequency stability of the local oscillators used to provide frequency translation of the received signals should be high, especially if the frequency of the modulation component in the output of a correlation device is to be used in deriving the speed or direction of motion of a source. Such stability may be obtained using a crystal or other frequency standard at each location with, if necessary, measurements of the drifts of the standard.

Each frequency analyser may for example be of the sweeping superhet type in which the signal to be analysed is mixed with a signal from a tunable local oscillator and the difference frequency is supplied to a filter having a very narrow pass-band, or it may be a Fast Fourier Analyser or a compressive receiver.

In the above description, the determination of whether the spectra of different correlation signals have at least one respective component representing the same difference between the Doppler shifts of corresponding signals received at two locations from the same source has been described as being performed by visual inspection of the displayed spectra, but the process may of course by performed automatically, for example by simultaneously analysing the same narrow frequency band of the different spectra and providing an indication when they each have a substantial component. The other processes required to determine the speed and/or direction of motion of a source may similarly be performed automatically.

According to a third aspect of the invention, a method of locating radiating radio sources with reference to a plurality of spaced locations, said sources moving relative to said locations, comprises:-

receiving radiated signals with radiation patterns of antenna means at said locations and deriving from corresponding signals radiated by the same moving radio source and received respectively at two said locations, the corresponding signals being within a predetermined narrow frequency band, a set of at least two correlation signals each representative of a correlation between the corresponding signals, wherein the correlation signals each have components at one or more frequencies dependent on the difference between the Doppler shifts of the corresponding signals received respectively at the two locations, wherein a first of the correlation signals is derived from corresponding signals received respectively with at least one radiation pattern at each of the two locations whereby to enable the location of at least one source to be ascertained approximately, and wherein a second of the correlation signals is derived from corresponding signals received respectively with said at least one radiation pattern at one of the two locations and with at least one further radiation pattern at the other of the two locations,

the method further comprising:-

obtaining an indication that the same said difference between the Doppler shifts is represented by at least one respective component of each correlation signal, whereby substantially to associate the same at least one source with said at least one respective component of each correlation signal and hence to enable the location thereof to be ascertained more precisely.

In such a method, at said other of the two locations, said at least one radiation pattern and said at least one further radiation pattern may be differently shaped, whereby to select different regions so that each of the two correlation signals represents the presence of at least one said source in a respective said region, the different regions overlapping so as to have in common a region of overlap that is smaller than at least one of said different regions, and whereby

obtaining said indication substantially establishes the presence of at least one source in the common region of overlap; this is a method encompassed in the first aspect of the invention. However, as an alternative in a method embodying the third aspect of the invention, at said other of said two locations, said one radiation pattern and said one further radiation pattern may be the respective radiation patterns of a pair of closely-spaced antennae, the method further comprising measuring the phase difference between said one respective component of each of the two correlation signals whereby to ascertain the angle of incidence of the radiated signals on said pair of antennae. This involves the recognition that the phase difference between said one respective component of each of the two correlation signals is representative of (in a simple case, equal to) the phase difference between the signals respectively incident on the pair of antennae from which the two correlation signals are respectively derived. The pair of antennae may, for example, be a pair of identical antennae mounted side-by-side so as to be scannable as a single unit about a common axis. As a general approximation, the range of angles over which the direction of incidence of radiation on such a pair of contiguous antennae may be determined unambiguously from the phase difference between the antennae is equal to the 3dB beamwidth of each antenna. This gives a method embodying only the third aspect of the invention the following advantage over a method embodying only the first aspect. Using a monopulse antenna having sum and difference radiation patterns, when the presence of at least one source within the sum pattern has been detected, the location of the source(s) may be established more precisely by scanning the difference pattern through the whole of the sector occupied by the 3dB beamwidth of the sum pattern (in the position in which the presence of the source(s) was detected) in steps of, say, one-tenth of that 3dB beamwidth; a correlation signal must be formed and its spectrum analysed for each position of the difference pattern. By contrast, using a pair of contiguous identical antennae, it is only necessary to form one pair of correlation signals and measure the phase differences between the corresponding components in their respective spectra in order to

locate all distinguishable sources lying within the 3dB beamwidth.

The third aspect of the invention provides a broader class of method than the first aspect for locating a source using two distinct radiation patterns at at least one (and preferably each) of the two locations, while using the same principle of associating or "labelling" individual sources, within the area of intersection of radiation patterns of antenna means respectively at the two locations, with components of the spectrum of a correlation signal derived from sources within that area.

It may be noted that locating a source relatively precisely with a method embodying the first aspect of the invention by scanning a radiation pattern so as to obtain a turning point in the magnitude of a component of a correlation signal, and with a method embodying the third aspect of the invention by measuring the phase difference between respective components, each associated with the same source, of two correlation signals, both involve deriving information from the amplitude and/or phase of one or more components of one or more correlation signals.

In a method embodying the third aspect of the invention, the direction of motion and/or speed of a said source may be derived by:-

deriving from corresponding signals radiated by the same said source and received respectively at one of said two locations and at a third said location, the corresponding signals being within the predetermined narrow frequency band, at least one further correlation signal representative of a correlation between received corresponding signals radiated by the same source as corresponding signals from which said two correlation signals are derived, and

deriving from at least one of said two correlation signals and from at least one said further correlation signal the respective differences between the Doppler shifts of the pairs of corresponding signals, radiated by the same said source, from which those correlation signals are derived.

Said respective differences between the Doppler shifts may be derived from said at least one of said two correlation

signals and said at least one said further correlation signal by identifying the respective components thereof which:-

(i) give matching bearings of a said source as determined with respect to the location from corresponding signals received at which both said at least one of said two correlation signals and said at least one said further correlation signal are derived, or

(ii) give matching locations of a said source as determined both with respect to said two locations and with respect to said third location and the one of said two locations from signals received at which said at least one further correlation signal is derived.

According to a fourth aspect of the invention, a system for locating radiating radio sources with reference to a plurality of spaced locations, said sources moving relative to said locations, comprises:-

at each of said locations, antenna means having at least one radiation pattern for receiving radiated signals;

means for predetermining a common narrow frequency band within the frequency range of reception of each radiation pattern;

means for deriving from corresponding signals radiated by the same moving radio source and received respectively at two said locations, the corresponding signals being within the predetermined frequency band, a set of at least two correlation signals each representative of a correlation between the corresponding signals;

wherein the correlation signals each have components at one or more frequencies dependent on the difference between the Doppler shifts of the corresponding signals received respectively at the two locations, wherein a first of the correlation signals is derived from corresponding signals received respectively with at least one radiation pattern at each of the two locations whereby to enable the location of at least one source to be ascertained approximately, and wherein a second of the correlation signals is derived from corresponding signals received respectively with said at least one radiation pattern at one of the two locations and with at least one further radiation pattern at the other of the two locations;

the system further comprising:-

means for indicating that the same said difference between the Doppler shifts is represented by at least one respective component of each correlation signal, whereby substantially to associate the same at least one source with said at least one respective component of each correlation signal and hence to enable the location thereof to be ascertained more precisely.

In such a system, at said other of the two locations, said one radiation pattern and said one further radiation pattern may be the respective radiation patterns of a pair of closely-spaced antennae, the system further comprising means for measuring the phase difference between said one respective component of each of the two correlation signals whereby to ascertain the angle of incidence of the radiated signals on said pair of antennae.

Methods and systems embodying the third and fourth aspects of the invention may be closely similar to those respectively embodying the first and second aspects. For example, referring to Figure 1, instead of having at each location A and B a steerable monopulse antenna 1 having feeders 2 and 3 respectively connected to two inputs of a hybrid device 4 whose outputs 5 and 6 are respectively connected to the inputs 7 of two circuit blocks P, there may be provided at each location A and B a steerable pair of contiguous identical antennae which are respectively directly connected to the inputs 7 of two circuit blocks P. The three correlation devices 16-18 may cross-correlate signals respectively derived from: a first of the antennae at A and at B; the first antenna at A and the second antenna at B; and the second antenna at A and the first antenna at B. The analysers 19-21 are suitably Fast Fourier Analysers which give both the amplitude and the phase (relative to an arbitrary reference value) of the analysed components of the correlation signals. In addition to the displays 22-24, there may be connected to the analysers 19-21 means for indicating the phase differences between corresponding components at the outputs of the analysers 19 and 20 and at the outputs of analysers 19 and 21 respectively. From the magnitudes and senses of these phase differences may be determined with good precision the angular disposition, with respect to boresight, of sources lying within

approximately the 3dB beamwidth of the first antenna at each location A and B, and hence, from the orientation of the antennae, the bearings of the sources with respect to A and B.

CLAIMS:

1. A method of locating radiating radio sources with reference to a plurality of spaced locations, said sources moving relative to said locations, the method comprising:-

receiving radiated signals with radiation patterns of antenna means at said locations and deriving from corresponding signals radiated by the same moving radio source and received respectively at two said locations, the corresponding signals being within a predetermined narrow frequency band, a set of at least two correlation signals each representative of a correlation between the corresponding signals, wherein the reception of the radiated signals and the derivation of the correlation signals includes the selection of different regions so that each correlation signal represents the presence of at least one said source in a respective said region, the different regions overlapping so as to have in common a region of overlap that is smaller than at least one of said different regions, and wherein the correlation signals each have components at one or more frequencies dependent on the difference between the Doppler shifts of the corresponding signals received respectively at the two locations, and

obtaining an indication that the same said difference between the Doppler shifts is represented by at least one respective component of each correlation signal,

whereby substantially to establish the presence of a said source in the common region of overlap.

2. A method as claimed in Claim 1 wherein said selection of different regions comprises the reception of radiated signals with at least two different radiation patterns of the antenna means at at least one of the two locations.

3. A method as claimed in Claim 1 or 2 further comprising scanning a said radiation pattern so as to obtain a turning point in

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the magnitude of at least one said respective component of a said correlation signal derived from a said signal received with the radiation pattern being scanned, whereby to locate a said source substantially at a turning point in the magnitude of the radiation pattern being scanned.

4. A method as claimed in Claim 3 wherein the method comprises scanning a said radiation pattern at each of said two locations so as to obtain substantially simultaneous turning points in the magnitudes of at least one said respective component of each of two said correlation signals derived from corresponding signals received with the radiation patterns being scanned respectively at the two locations, the same said difference between Doppler shifts being represented by at least one such respective component of each of the two correlation signals, whereby to locate a said source substantially at a respective turning point in the magnitude of each of the radiation patterns being scanned.

5. A method as claimed in any preceding claim wherein a said radiation pattern has a single narrow main lobe.

6. A method as claimed in any preceding claim wherein a said radiation pattern has a pair of closely-spaced narrow main lobes.

7. A method as claimed in Claim 5 and Claim 6 wherein a first of the correlation signals is derived from corresponding signals received at each of the two locations with a respective radiation pattern having a single narrow main lobe, and wherein a second of the correlation signals is derived from corresponding signals received respectively at a first of the two locations with a radiation pattern having a single narrow main lobe and at the second location with a radiation pattern having a pair of closely-spaced narrow main lobes.

8. A method as claimed in Claim 7 wherein a third correlation signal is derived from corresponding signals received respectively at the first location with a radiation pattern having a pair of closely-spaced narrow main lobes and at the second location with a radiation pattern having a single narrow main lobe.

9. A method as claimed in Claim 8 as appendant to Claim 4 wherein at each of the two locations, the radiation pattern having a pair of

closely-spaced narrow main lobes is scanned, and wherein said substantially simultaneous turning points are minima, whereby to locate said source substantially at the minima in the magnitudes of the radiation patterns between the two main lobes of each pair.

10. A method as claimed in any preceding claim further comprising

deriving from corresponding signals radiated by the same said source and received respectively at one of said two locations and at a third said location, the corresponding signals being within the predetermined narrow frequency band, at least one further correlation signal representative of the presence of said source in a respective further region including at least part of said common region of overlap, and

deriving from at least one of said set of correlation signals and from at least one said further correlation signal the respective differences between the Doppler shifts of the pairs of corresponding signals, radiated by the same said source, from which those correlation signals are derived,

whereby to derive the direction of motion and/or speed of said source.

11. A method as claimed in Claim 10 which comprises the process of scanning at one of said two locations a radiation pattern receiving radiated signals from which one of said set of correlation signals and a said further correlation signal are derived, and deriving said respective differences between the Doppler shifts of the pairs of corresponding signals from the frequencies of the respective components of those correlation signals that have simultaneous turning points as the radiation pattern is scanned.

12. A method as claimed in Claim 11 wherein, in said process, each of those correlation signals has a plurality of components that have simultaneous turning points as the radiation pattern is scanned, and wherein the method further comprises determining for each of those correlation signals the frequency about which the respective frequencies of its components having simultaneous turning points are symmetrical.

13. A method as claimed in any preceding claim wherein the frequencies of corresponding signals received at each of the two locations

within the predetermined narrow frequency band are subjected to respective frequency translations differing by an amount greater than the largest said difference between the Doppler shifts to be detected.

14. A system for locating radiating radio sources with reference to a plurality of spaced locations, said sources moving relative to said locations, the system comprising

at each of said locations, antenna means having a radiation pattern for receiving radiated signals;

means for predetermining a common narrow frequency band within the frequency range of reception of each radiation pattern;

means for deriving from corresponding signals radiated by the same moving radio source and received respectively at two said locations, the corresponding signals being within the predetermined frequency band, a set of at least two correlation signals each representative of a correlation between the corresponding signals;

wherein the aforesaid means comprise means for selecting different regions so that each correlation signal represents the presence of at least one said source in a respective said region, the different regions overlapping so as to have in common a region of overlap that is smaller than at least one of said different regions, and wherein the correlation signals each have components at one or more frequencies dependent on the difference between the Doppler shifts of the corresponding signals received respectively at the two locations, and

means for indicating that the same said difference between the Doppler shifts is represented by at least one respective component of each correlation signal,

whereby substantially to establish the presence of a said source in the common region of overlap.

15. A system as claimed in Claim 14 wherein said means for selecting different regions comprises at least two different radiation patterns of the antenna means at at least one of the two locations.

16. A system as claimed in Claim 14 or 15 wherein the antenna means at at least one of the two locations is operable to scan a said radiation pattern and wherein the apparatus is operable to indicate a turning point in the magnitude of at least one said respective component of a said correlation signal derived from a said signal received with the radiation pattern being scanned, whereby to locate a

said source substantially at a turning point in the magnitude of the radiation pattern being scanned.

17. A system as claimed in Claim 16 wherein the antenna means at each of the two locations is operable to scan a respective said radiation pattern and wherein the system is operable to indicate substantially simultaneous turning points in the magnitudes of at least one said respective component of each of two said correlation signals derived from corresponding signals received with the radiation patterns being scanned respectively at the two locations, the same said difference between Doppler shifts being represented by at least one such respective component of each of the two correealtion signals, whereby to locate a said source substantially at a respective turning point in the magnitude of each of the radiation patterns being scanned.

18. A system as claimed in any of Claims 14 to 17 wherein a said radiation pattern has a single narrow main lobe.

19. A system as claimed in any of Claims 14 to 18 wherein a said radiation pattern has a pair of closely-spaced narrow main lobes.

20. A system as claimed in Claims 18 and 19 wherein the antenna means at each of the two locations has a first radiation pattern with a single narrow main lobe and a second radiation pattern with a pair of closely-spaced narrow main lobes, and wherein said means for deriving a set of at least two correlation signals is operable to respectively cross-correlate signals derived from a said source using the first and second radiation patterns respectively at a first of the two locations with signals derived from the same said source using the second and first radiation patterns respectively at the second location.

21. A system as claimed in Claims 18 and 19 or in Claim 20 wherein the antenna means, at least at each of the two locations, comprises a monopulse antenna with two scannable radiation patterns, namely a sum radiation pattern having said single narrow main lobe and a difference radiation pattern having said pair of closely-spaced narrow main lobes.

22. A system as claimed in Claim 21 wherein said means for deriving

a set of at least two correlation signals is operable to cross-correlate signals derived respectively using the sum pattern at each of the two locations with one another, and to cross-correlate signals derived respectively using the sum pattern at each one of the two locations with signals derived respectively using the difference pattern at each other of the two locations.

23. A system as claimed in Claim 15 or any preceding claim appendant thereto wherein said means for deriving a set of at least two correlation signals comprises delay means for delaying a signal derived using a radiation pattern at one of the two locations by a selected one or more of a plurality of different delay times relative to a signal derived using a radiation pattern at the other of the two locations, means for multiplying the relatively undelayed signal with the signal relatively delayed by the selected one delay time or separately with the signal as respectively relatively delayed by each of the selected delay times, means for controlling the orientations of the radiation patterns of the antenna means at the two locations, and means for selecting said one or more delay times in accordance with said orientations so that in operation said different regions are selected substantially wholly by said different radiation patterns.

24. A system as claimed in any of Claims 14 to 23 comprising means for deriving from corresponding signals radiated by the same said source and received respectively at one of the two locations and at a third said location, the corresponding signals being within the predetermined narrow frequency band, at least one further correlation signal representative of the presence of said source in a respective further region including at least part of said common region of overlap, and means for deriving from at least one of said set of correlation signals and from at least one said further correlation signal the respective differences between the Doppler shifts of the pairs of corresponding signals, radiated by the same said source, from which those correlation signals are derived, whereby to derive the direction of motion and/or speed of said source.

25. A system as claimed in any of Claims 14 to 24 comprising means for subjecting the frequencies of corresponding signals received at each of the two locations within the predetermined narrow frequency band to respective frequency translations differing by an amount greater than the largest said difference between the Doppler shifts to be detected.

26. A method of locating radiating radio sources with reference to a plurality of spaced locations, said sources moving relative to said locations, the method comprising:-

receiving radiated signals with radiation patterns of antenna means at said locations and deriving from corresponding signals radiated by the same moving radio source and received respectively at two said locations, the corresponding signals being within a predetermined narrow frequency band, a set of at least two correlation signals each representative of a correlation between the corresponding signals, wherein the correlation signals each have components at one or more frequencies dependent on the difference between the Doppler shifts of the corresponding signals received respectively at the two locations, wherein a first of the correlation signals is derived from corresponding signals received respectively with at least one radiation pattern at each of the two locations whereby to enable the location of at least one source to be ascertained approximately, and wherein a second of the correlation signals is derived from corresponding signals received respectively with said at least one radiation pattern at one of the two locations and with at least one further radiation pattern at the other of the two locations, the method further comprising:-

obtaining an indication that the same said difference between the Doppler shifts is represented by at least one respective component of each correlation signal, whereby substantially to associate the same at least one source with said at least one respective component of each correlation signal and hence to enable the location thereof to be ascertained more precisely.

27. A method as claimed in Claim 26 wherein at said other of the two locations, said at least one radiation pattern and said at least one further radiation pattern are differently shaped, whereby to select different regions so that each of the two correlation signals represents the presence of at least one said source in a

respective said region, the different regions overlapping so as to have in common a region of overlap that is smaller than at least one of said different regions, and whereby obtaining said indication substantially establishes the presence of at least one source in the common region of overlap.

28. A method as claimed in Claim 26 wherein at said other of the two locations, said one radiation pattern and said one further radiation pattern are the respective radiation patterns of a pair of closely-spaced antennae, the method further comprising measuring the phase difference between said one respective component of each of the two correlation signals whereby to ascertain the angle of incidence of the radiated signals on said pair of antennae.

29. A method as claimed in Claim 26 or 28 further comprising:-

deriving from corresponding signals radiated by the same said source and received respectively at one of said two locations and at a third said location, the corresponding signals being within the predetermined narrow frequency band, at least one further correlation signal representative of a correlation between received corresponding signals radiated by the same source as corresponding signals from which said two correlation signals are derived, and

deriving from at least one of said two correlation signals and from at least one said further correlation signal the respective differences between the Doppler shifts of the pairs of corresponding signals, radiated by the same said source, from which those correlation signals are derived,

whereby to derive the direction of motion and/or speed of said source.

30. A method as claimed in Claim 29 wherein said respective differences between the Doppler shifts are derived from said at least one of said two correlation signals and said at least one said further correlation signal by identifying the respective components thereof which give matching bearings of a said source as determined with respect to the location from corresponding signals received at which both said at least one of said two correlation signals and said at least one said further correlation signal are derived.

31. A method as claimed in Claim 29 wherein said respective differences between the Doppler shifts are derived from said at least

one of said two correlation signals and said at least one said further correlation signal by identifying the respective components thereof which give matching locations of a said source as determined both with respect to said two locations and with respect to said third location and the one of said two locations from signals received at which said at least one further correlation signal is derived.

32. A system for locating radiating radio sources with reference to a plurality of spaced locations, said sources moving relative to said locations, the system comprising:-

at each of said locations, antenna means having at least one radiation pattern for receiving radiated signals;

means for predetermining a common narrow frequency band within the frequency range of reception of each radiation pattern;

means for deriving from corresponding signals radiated by the same moving radio source and received respectively at two said locations, the corresponding signals being within the predetermined frequency band, a set of at least two correlation signals each representative of a correlation between the corresponding signals;

wherein the correlation signals each have components at one or more frequencies dependent on the difference between the Doppler shifts of the corresponding signals received respectively at the two locations, wherein a first of the correlation signals is derived from corresponding signals received respectively with at least one radiation pattern at each of the two locations whereby to enable the location of at least one source to be ascertained approximately, and wherein a second of the correlation signals is derived from corresponding signals received respectively with said at least one radiation pattern at one of the two locations and with at least one further radiation pattern at the other of the two locations;

the system further comprising:-

means for indicating that the same said difference between the Doppler shifts is represented by at least one respective component of each correlation signal, whereby substantially to associate the same at least one source with said at least one respective component of each correlation signal and hence to enable the location thereof to be ascertained more precisely.

33. A system as claimed in Claim 32 wherein at said other of the two locations, said at least one radiation pattern and said at least one further radiation pattern are differently shaped, whereby to select different regions so that each of the two correlation signals represents the presence of at least one said source in a

respective said region, the different regions overlapping so as to have in common a region of overlap that is smaller than at least one of said different regions, and whereby obtaining said indication substantially establishes the presence of at least one source in the common region of overlap.

34. A system as claimed in Claim 32 wherein at said other of the two locations, said one radiation pattern and said one further radiation pattern are the respective radiation patterns of a pair of closely-spaced antennae, the system further comprising means for measuring the phase difference between said one respective component of each of the two correlation signals whereby to ascertain the angle of incidence of the radiated signals on said pair of antennae.

35. A system as claimed in Claim 32 or 34 comprising means for deriving from corresponding signals radiated by the same said source and received respectively at one of the two locations and at a third said location, the corresponding signals being within the predetermined narrow frequency band, at least one further correlation signal representative of a correlation between received corresponding signals radiated by the same source as corresponding signals from which said two correlation signals are derived, and means for deriving from at least one of said two correlation signals and from at least one said further correlation signal the respective differences between the Doppler shifts of the pairs of corresponding signals, radiated by the same said source, from which those correlation signals are derived, whereby to derive the direction of motion and/or speed of said source.

36. A method of locating radio sources, substantially as herein described with reference to the accompanying drawings.

37. A system for locating radio sources, substantially as herein described with reference to the accompanying drawings.

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tents Act 1977
Examiner's report to the Comptroller under Section 17 (The Search Report)

Application number 8306191.1

Relevant Technical fields

(i) UK Cl (Edition E) H4D (DF and DR)

(ii) Int Cl (Edition) NONE

Databases (see over)

(i) UK Patent Office

(ii)

Search Examiner

H E GRIFFITHS

Date of Search

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Documents considered relevant following a search in respect of claims 1 to 37

Category (see over)	Identity of document and relevant passages	Relevant to claim(s)
	NONE	

SF2(p)

Category	Identity of document and relevant passages	Relevant to claim(s)

Categories of documents

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